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SUMMARY

The use of an aircraft as a test vehicle to produce a zero-gravity or weightless environment by flying a Keplerian trajectory is discussed. The experience gained with a converted, high-altitude bomber during 3 years of operation as a zero-gravity flight facility is employed to illustrate this technique and to explain the operational problems encountered. The duration of the weightless environment is determined solely by the magnitude of the angles and velocities with which the aircraft enters and exits the trajectory. Durations of up to 20 seconds have been achieved with this aircraft. Although most of the experience with this aircraft has been with a restrained installation of the experiments, a comparison is made of this mode with free-float and tethered modes of mounting experiments. With respect to other current methods of achieving a weightless state, the use of an aircraft as a weightless environment laboratory has distinct advantages when cost per experiment is considered, and when delicate handling of test equipment is necessary. The aircraft permits a large number of tests to be made in a short time. The facility also is a useful tool in the development and prelaunch testing of experiments that require the extended duration of weightlessness available only with rocket vehicles. The primary limitations of the use of an aircraft as a zero-gravity test facility are the disturbances introduced to the experiment during the maneuver entry prior to the weightless period and the requirement that the experiment be fabricated to withstand the loadings placed on it during pullup. However, these loadings are usually less than those associated with, for instance, drop-tower arrestment, or rocket launching.

INTRODUCTION

Although a vehicle in space never completely escapes the attraction of the numerous bodies in the universe, the net acceleration that it experiences becomes negligible as the distances between the bodies become large. This environment presents man with physical and physiological conditions that are unique to his traditional experience and thus

TABLE I. - COMPARISON OF FACILITIES FOR ZERO-G TESTING

Facility	Relative operating cost	Typical duration, sec	Remarks
Drop tower	Low to medium	5 - 10	Basic facility cost high for sophisticated system; very low g level
Aircraft	Low	15 - 90	Can be flown to location of experiment sponsor; has inherent disturbances that limit minimum g level
Suborbital rocket	High	600 - 4200	Costly; long prelaunch time

require experimental study. Several techniques for providing a weightless environment on the Earth have been in use for the past few years. In order of increasing duration of the gravity-free period these are: (1) controlled free-fall in a drop tower, (2) Keplerian trajectory maneuvers by an aircraft, and (3) ballistic flight by a rocket-launched vehicle. A representative sample of the literature concerned with zero-gravity facilities is contained in reference 1. The complementary use of these facilities in the study of the behavior of liquid hydrogen in a weightless environment is described in reference 2.

A comparison of the cost of operation and the weightless durations that are typical for each of the facilities is shown in table I. It is interesting to note that the methods exceed each other in environment duration by approximately one order of magnitude. Each of the techniques has its own area of usefulness and limitations in the spectrum of gravity-free environment.

This report will discuss the use of an aircraft as a test vehicle to produce a weightless environment. The experience gained from the use of a converted, high-altitude bomber over a 3-year period as a zero-gravity flight facility will be used to illustrate the usefulness of this technique and to explain the problems encountered during its operation. References 3 to 5 contain examples of studies made in the environment provided by this aircraft.

METHOD OF OPERATION

All currently known methods of producing a weightless environment in the vicinity of a major body, such as the Earth, require the production of an acceleration equal and opposite to the gravitational acceleration. An opposition acceleration can be created by flying an aircraft along an elliptical or Keplerian trajectory. For the purpose of analysis, a parabolic path has been considered as an approximation of the Keplerian trajectory,

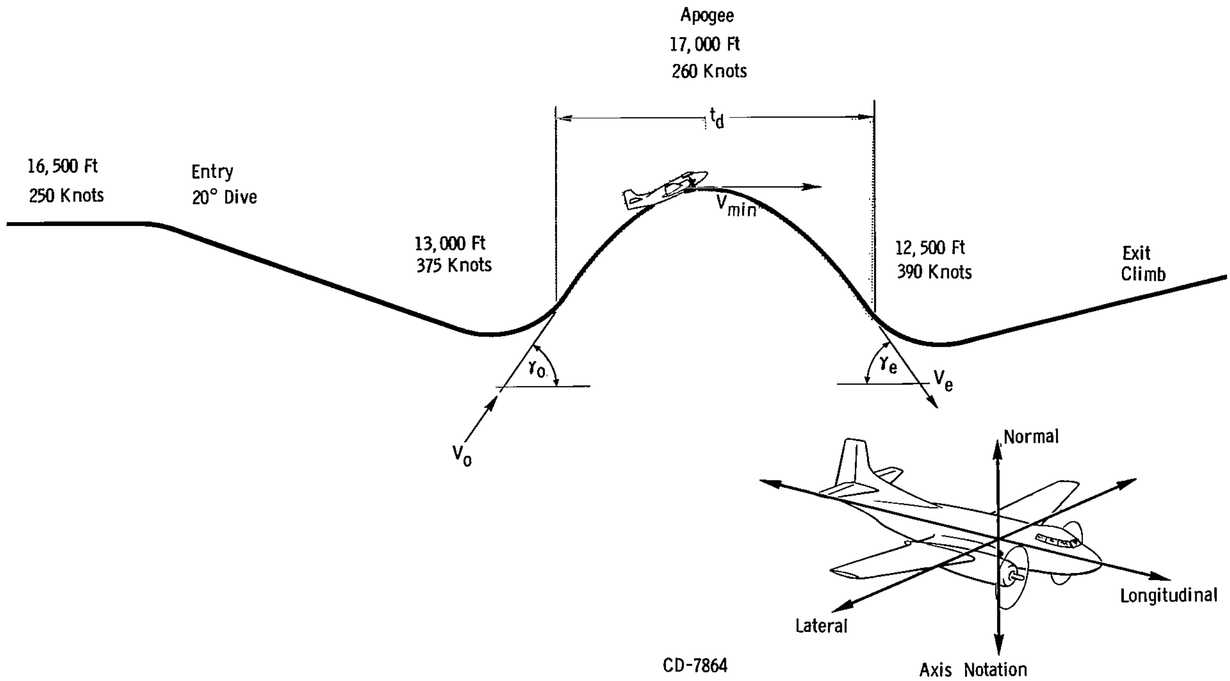

Figure 1. - Flight pattern used by Lewis flight facility for production of weightless environment. Speeds noted as true airspeed in knots.

and the path flown by an aircraft in this maneuver is shown in figure 1. The trajectory is achieved by placing the aircraft in a climbing attitude at a high speed and nulling all accelerations. The aircraft and its contents are then in a state of free fall for the duration of the nulled acceleration. Accomplishment of this seemingly simple maneuver in an acceptable manner becomes, however, a difficult piloting task.

Examination of the maneuver will define some of the performance requirements for the aircraft. As shown in figure 1, the aircraft enters the trajectory at an entry angle γ_o and an entry velocity V_o. For a ballistic path, the horizontal velocity component must remain constant; that is, $V_x = V_o \cos \gamma_o = \text{constant}$. The vertical component of velocity, $V_y = V_o \sin \gamma_o - gt$,* varies from an initial value equivalent to the terminal velocity of free fall, decreases to zero at the top of the trajectory, and then increases again to the free-fall terminal velocity for the vertical distance traversed. The theoretical duration of a symmetrical gravity-free trajectory is twice the time of free-fall of a body at rest to a final velocity equal to the initial vertical velocity component. The duration of the symmetrical maneuver may be expressed as $t_d = (2V_o \sin \gamma_o)/g$. The altitude change during the maneuver is sufficiently small that g is assumed to be constant. Further discussion of the trajectory is contained in the aircraft flight section of reference 6.

*Positive and negative values are assumed by t with $t = 0$ at apogee.

It may therefore be seen that the duration of the weightless environment obtainable in an aircraft is determined by the magnitude of the entry angle (γ_o), the entry velocity (V_o), the exit velocity (V_e), and the acceleration due to gravitational attraction. If a symmetrical flight path ($V_o = V_e$) is assumed, the angle at which the aircraft exits the trajectory V_e is theoretically equal to the angle at which it enters the maneuver. For an asymmetrical parabola, where the entry and exit angles are not equal, the computation of the total weightless duration must consider the times obtained separately from the two unequal portions of the parabola.

The entry speed V_o and the minimum maneuver speed V_{min} determine the entry angle V_o. The minimum speed that the aircraft experiences during the maneuver occurs at the top of the trajectory. Ideally, for a given maximum allowable airspeed, the maximum weightless duration will occur when the entry and exit velocities are equal to V_{max} for the particular aircraft and an entry angle of 90^o. This of course is impossible since it represents a maneuver minimum speed V_{min} of zero and requires an instantaneous 180^o reversal of aircraft attitude. Therefore, a compromise must be made, which reflects the practical capability of the aircraft. This not only includes speed, structural, and aerodynamic considerations, but also controllability. The weightless duration t_d will be maximized when the difference between the two extreme speeds (V_{max} - V_{min}) is a maximum. The maximum speed of the aircraft is a function of the power available, structural design, and aerodynamic drag, while the maneuver minimum speed usually is determined by the controllability of the aircraft. This minimum control speed may in this case be less than the normal 1 g environment stalling speed of the aircraft and must be determined by actual flight tests of the particular aircraft to be used.

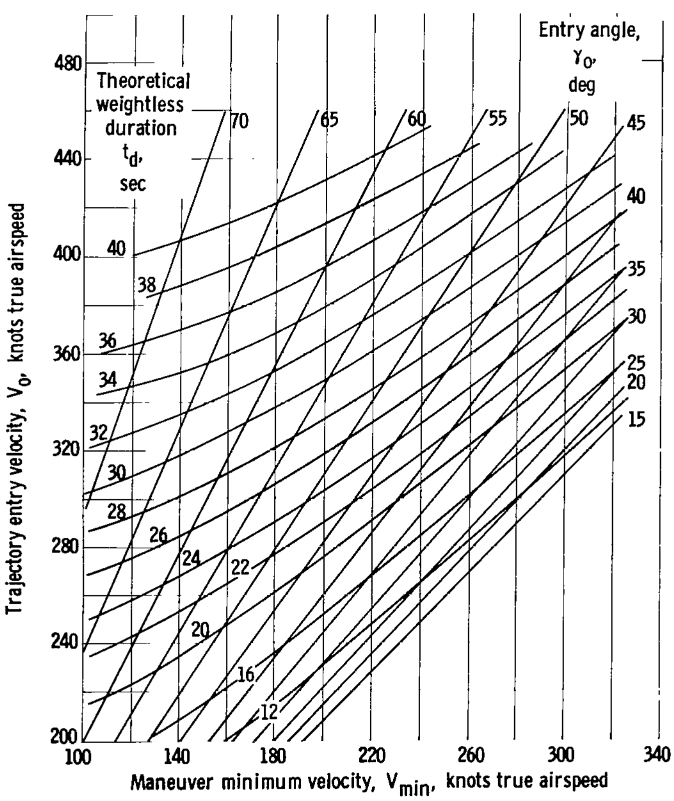

Figure 2. - Theoretical weightless duration achieved by aircraft maneuver.

The theoretical weightless duration as a function of the trajectory entry velocity, the maneuver minimum velocity, and the entry angle is presented in figure 2, which describes a family of Keplerian trajectories. This grid is independent of the type aircraft used. Several uses may be made of this figure. Given a

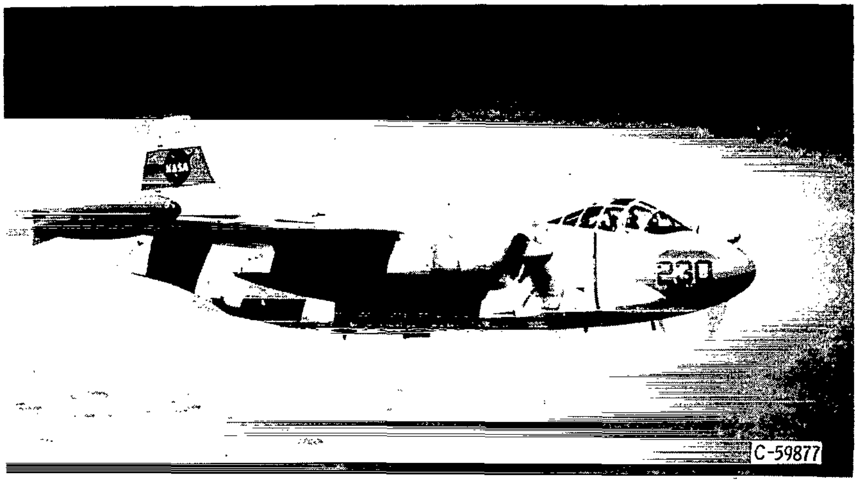

Figure 3. - AJ2 aircraft converted for use as zero-gravity flight facility.

desired zero-g duration, the required entry angles and associated velocities are delineated. Conversely, the maximum and minimum velocities can be used to determine a resulting weightless duration and the entry angle necessary for achieving it. For example, it appears that significantly longer times could be achieved by entering and exiting the maneuver at high angles. Practice has shown, however, that at angles much greater than 50°, the pilot's control task becomes more difficult, responsewise, so that the quality of the trajectory suffers intolerably. With an automatic flight controller, this limitation of entry angle could be raised significantly and a 10 to 15 percent increase in weightless duration could be expected. Although figure 2 establishes criteria for defining the particular flight pattern for maximum zero-gravity duration for any aircraft, considerable refinements are required for application to a particular aircraft. These will be reviewed using an AJ2 aircraft (fig. 3) for examples.

OPERATIONAL CONSIDERATIONS

The maneuver trajectory used by the Lewis AJ2 aircraft with the related altitudes and airspeeds is shown in figure 1. In preparation for the maneuver, the aircraft is trimmed for cruise at level flight and the entire trajectory is flown without change in the longitudinal trim. Climb power is set and a dive of approximately 20° is begun in order to reach an airspeed of 375 knots at 13 000 feet. The aircraft is then rotated at $2\frac{1}{2}$ g's to a pitch attitude of about 40°, the entry angle. During this pullup, a 10- to 15-knot degradation in velocity is experienced due to the increased induced drag. Upon entering the maneuver, the longitudinal acceleration is nulled by manually modulating the power. The normal and lateral accelerations are continually nulled by application of conventional aerodynamic control forces. This manually integrated control is maintained by the pilot throughout the trajectory. His skill in this operation is directly reflected in the quality of minimum g-level of the weightless environment produced.

The apogee of the trajectory is reached at about 17 000 feet with an airspeed of 260 knots. On the descent portion of the trajectory, power is added as the speed increases. When a 45° dive angle is reached at about 390 knots, a $2\frac{1}{2}$-g pullup is made, and the exit climb is begun to the premaneuver altitude. This maneuver results in an asymmetric trajectory and theoretically produces a weightlessness duration of 27 seconds. Practice has shown that the aircraft can be manually held to 0 ± 0.05 g along the normal axis for a majority of this time. This trajectory is similar to and the performance compares favorably with that achieved by the USAF propeller aircraft facility reported in reference 7.

An unpredictable factor affecting the quality of the weightless environment is weather. Unstable air masses can degrade the trajectory quality because of the inability of the pilot to react to wind gusts and local perturbations. Because the trajectory traverses an altitude band of about 4000 feet, wind shear can have a further influence on the quality of the environment. Cloud cover under the operating altitudes generally does not present a problem. Stable air conditions can occur with solid cloud undercasts, and the Lewis tests were frequently flown with these conditions. It is only necessary that sufficient altitude exist between the maneuver altitude block and the cloud layer to permit safe recovery from the trajectory.

Nothing in the experience of operating the facility at the Lewis Research Center indicates that any unusual stress is placed upon the flight crew or test observers, aside from an occasional incidence of motion sickness. It was found that the breathing of pure oxygen suppressed the onset of motion sickness for most observers. The only unusual physiological conditions faced were those associated with altitude flying. It was found that, if the observers were indoctrinated for flight at altitudes requiring the use of oxygen, no further specialized training was required for operation aboard the facility.

In the Lewis facility, the observer normally occupies a windowless bomb bay in which he has only his kinesthetic sense for spatial orientation. He usually feels he is in straight and level flight and only senses fluctuations in g-level. The aircraft bomb bay is unpressurized, and oxygen is required at altitudes above 10 000 feet.

AIRCRAFT SUITABILITY

The selection of a particular aircraft as a zero-gravity facility involves consideration of many factors such as performance, size, and maneuverability. The more significant of these factors will be discussed; and where applicable, the AJ2 experience will be cited as exemplary.

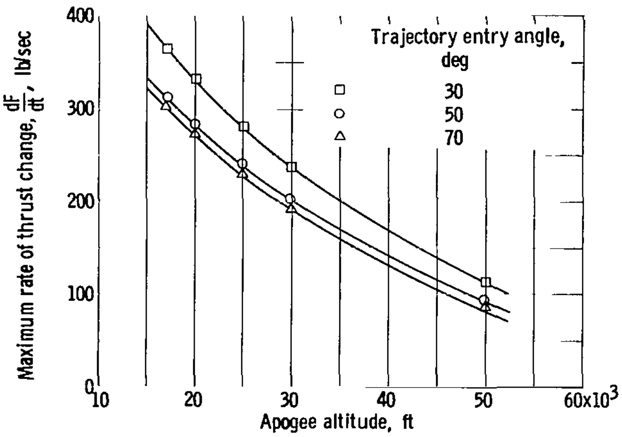

Figure 4. - Maximum rate of thrust change for AJ2 aircraft computed for 25-second zero-gravity duration trajectory.

It has been shown that the aircraft must have sufficient performance in the form of power or thrust to achieve a precise speed and angle for trajectory entry as well as to overcome coordinate acceleration. Some deficiency in maximum power can be overcome by the use of a dive at maximum power prior to trajectory entry, as is shown in figure 1 (p. 3). At this point an immediate power reduction is made to null the longitudinal acceleration. A similar operation is used during trajectory recovery although the power requirements vary through the maneuver; the most stringent power response rates are in the entry and exit maneuvers. If the power response demand is not met, the acceleration fluctuations in the longitudinal direction will not be eliminated. The maximum thrust response required for a 25 second zero-gravity duration aboard the AJ2 is shown in figure 4. The magnitude of the thrust response is a function of the airplane drag characteristics and thus related to the flight velocity and altitude (air density). The maximum response rate is related to the trajectory entry velocity and the associated entry angles, as well as the apogee altitude. Figure 4 shows that the thrust response is not greatly influenced by the entry angle for angles between 30° and 70°. It varies more widely with apogee altitude because of the nonlinear variation of air density (thus, drag) with altitude. Although trajectories with very high altitude apogees appear quite favorable, aircraft are usually limited by practical considerations. For instance, the AJ2 was limited to apogees below about 17 000 feet because the observer's area is not a pressurized compartment.

From the flight control standpoint, the aircraft characteristics will determine the amount of trim change required to meet the speed and attitude requirements of the maneuver. In some cases, the amount of trim change and the forces acting on the control surfaces that are sensed by the pilot might be prohibitively excessive unless some modifications are made to the basic aircraft control system. This becomes more critical when entering the trajectory at high velocities and angles. Controllability at the maneuver minimum speeds is a problem also, because aircraft control surfaces become less effective at slower speeds. This is particularly important in meeting the angular changes required in the pitch direction during the trajectory. If the slow speed control problem becomes oppressive, increasing the minimum velocity will increase controllability at a cost of decreased zero-g environment duration.

Although normal thrust responses available with the AJ2 to nullify the longitudinal

TABLE II. - AIRCRAFT THAT MIGHT BE USED AS ZERO-GRAVITY FACILITIES

Aircraft	Theoretical weightless duration, t_d, sec	Typical compartment dimensions, width × height × length, ft
F104 (fighter)	90	1 × 2 × 1
B66 (bomber)	50	6 × 6 × 14
C141 (transport)	40	10 × 9 × 1
KC135 (transport)	35	8 × 6 × 30
AJ2 (bomber)	30	5 × 5 × 13
C130 (transport)	26	10 × 9 × 10
C131 (transport)	15	7 × 6 × 25
C47 (transport)	6	6 × 6 × 20

accelerations have proved acceptable for this maneuver the weightless environment time could be increased about 10 or 15 percent by the use of an automatic drag and thrust control device. Such a system has been designed and is described in reference 8.

Another significant factor in determining the suitability of a particular aircraft as a zero-gravity facility is the volume of space available for the experiment. In the case of free-floated experiments, it is desirable to have the unobstructed volume as large as possible in relation to the size of the free-floated experiment package. Table II shows some representative aircraft that might be considered as zero-gravity facilities. The C47 transport, familiar to all, has been included to demonstrate that, although it has a favorable compartment volume, the duration of the weightless period is so small as to preclude its use. On the other hand, the smaller fighter type aircraft, which have a high thrust-to-weight capability, are ideal from the standpoint of duration of zero-gravity (60 to 90 sec) and maneuverability, but has a small volume and cannot accommodate a free-floated experiment of any but the smallest size.

The AJ2 aircraft (see fig. 3, p. 5) is equipped with three engines; two reciprocating engines and a turbojet engine mounted in the rear fuselage section. The aircraft can accommodate a crew of four: pilot, flight engineer, and two observers. The bomb bay is readily accessible in flight and is equipped with oxygen outlets and communications. Provisions have been made for heating the experiment area with air bled from the jet-engine compressor. The aircraft has been equipped with a 100-liter cryogenic Dewar and distribution system for those experiments requiring special cooling. Both television and 16-millimeter motion-picture cameras are used for observation.

The following subsystems aboard the AJ2 aircraft were found to be critical during gravity-free operation and were thoroughly investigated for required modifications: (a) fuel system, (b) engine oil system, (c) flight control boost hydraulic system, (d) propeller governing system, and (e) miscellaneous components such as batteries, combustion heater, etc. These systems all involve fluids. There are techniques available for working with fluids in the absence of gravity for short periods of time, and for gross considerations, such operations are totally within the present state of the art.

The AJ2 aircraft fuel lines from the tanks to the engines are sufficiently long that a sump for almost 55 seconds of engine operation is provided. This is over twice as much as required; consequently, no modification was made. In experience totaling over 1200 trajectories, no instance of engine fuel starvation has occurred.

While the jet engine lubrication problem is not serious for weightless durations of 60 seconds or less, it is critical, however, for reciprocating engines because the oil system provides not only lubrication, but a heat sink, also. Interruption of oil flow, especially at high power settings, could cause catastrophic engine damage. The provision of an auxiliary oil system is necessary. On the AJ2 aircraft this was accomplished by using a positive expulsion system employing a free-piston accumulator. Over 1500 successful cyclings of the system during development and actual use attest to its reliability. The AJ2 aircraft is equipped with a turbosupercharger system that has an independent oil system. Because lubrication is accomplished by introducing the oil in mist form to the bearings and the scavenge pump capacity is about four times that of the supply pump, the oil is returned to the reservoir in a frothed condition. Normal overpressure exists in the reservoir, and during the maneuver oil is forced overboard. To overcome this, a simple centrifugal separator was installed to separate the air and oil and allow venting of the air.

The propeller governing system is another potential source of difficulty in weightless operation. Hydraulic systems must be inspected for possible malfunctioning during zero-g operation. Propellers with electronic speed sensing and control devices present less difficulty.

As with any aircraft used for an acrobatic maneuver, the zero-gravity facility is given increased attention to detect potential structural failure areas. The high loadings occur during the entry pullup and at recovery from the maneuver. The peak loading of the recovery maneuver can be varied by increasing or decreasing the time used to recover; however, the increased induced drag during a high-g recovery negates the advantage of the reduced recovery time, so the lower loading appears more desirable.

Fatigue is of prime importance here. The airframe is regularly cycled from a $2\frac{1}{2}$ g condition to a completely unloaded state. These cyclic fluctuations of load have a negative influence on the fatigue life of the airframe.

Fatigue life of an aircraft structure is very difficult to predict because of many unknown factors (see ref. 9). The cyclic loads of this maneuver must be superimposed on the gust loads normally encountered in flight with the result that the normal fatigue life expectancy of the airframe is reduced. The fatigue-critical portions of the AJ2 aircraft are the outer wing panels, the main wing spar, the horizontal stabilizer, and the landing gear uplock. Therefore, a schedule of structural inspections has been set up to permit early detection of any incipient failure. The critical components are inspected after every 30 hours of flying. Detailed X-ray analysis was made of all the critical areas of the aircraft following the 1200th trajectory as suggested by the manufacturer. The X-ray examination revealed no structural deficiencies.

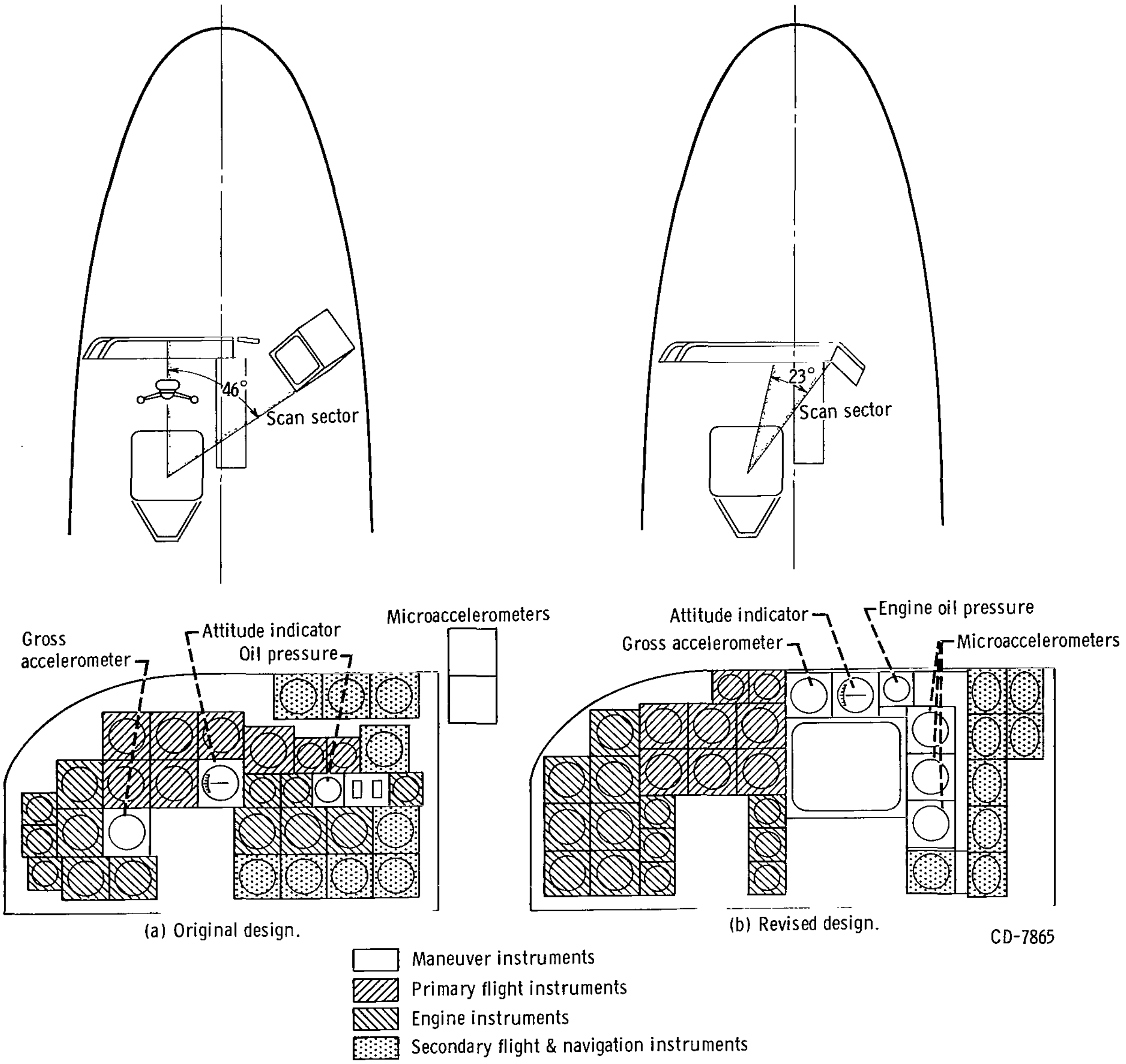

Figure 5. - AJ2 aircraft instrument display.

Because of the g-level variations encountered during this maneuver, some instrumentation and pilot displays in addition to that normally found aboard an aircraft are necessary. The limits of manual controllability are approached in this maneuver, and the pilot needs all the instrument assistance available. The instrumentation used aboard the AJ2 aircraft evolved through several stages of displays and recording devices. While more elaborate instruments were being prepared, a simple free-floating device consisting of a ping-pong ball on a string proved to be a suitable reference in entering and maintaining the gravity-free period. Use of a similar instrument (a floating cork) is reported in reference 7. Using these devices, the pilot can concentrate on flying around the ball in free-fall without reference to other instruments. Quantitatively, however, this was found to be unsuitable for experimental purposes because, among other reasons, of the location of the sensor. Because of the pitch rotation of the aircraft, the cockpit achieves zero gravity before the bomb bay and must be at a slightly negative value to place the experiment area in zero gravity. The installation of sensitive accelerometers at the center of gravity of the aircraft provides acceleration data for analysis about all three axes.

To provide observation of the experiment by the pilot and flight engineer during the maneuver, a 14-inch television monitor had been installed in the cockpit in front of the flight engineer's station. Location of the television monitor and flight instruments is shown in figure 5(a). During recovery from the initial dive at start of trajectory, the pilot's primary reference is the attitude indicator. During the transitional period he must shift his attention to the accelerometers and the television monitor. This necessitated orienting his head about 45° to the right and scanning back to the attitude and airspeed indicators. Occasionally the head movement associated with wide scan produced mild vertigo resulting in control input disturbances adversely affecting the duration and quality of zero gravity during the maneuver. To alleviate this condition the aircraft standard instrument panel was redesigned with a functional regrouping of instruments to reflect the needs of the specialized maneuver. The revised instrument display is shown in figure 5(b). The primary aim of the redesign was to minimize the pilot's head movement during instrument scan and thus improve the quality of the maneuver. One feature was the incorporation of an 8-inch television monitor, which replaced the larger off-center screen. This was positioned slightly right of center on the panel with the pitch indicator and the three sensitive microammeters, which display the accelerations along the reference axes. This functional regrouping resulted immediately in an increase in zero-gravity environment duration. The instrument display was revised between flight run numbers 49 and 50. The performance improvement is shown in figure 6. The data shown here are for the free-float mode and are of shorter duration than those achieved with restrained mode, as will be discussed in the following section. Not only did the maximum zero-gravity duration increase to as much as 11.5 seconds for some trajectories, but also the mean duration periods more than doubled.

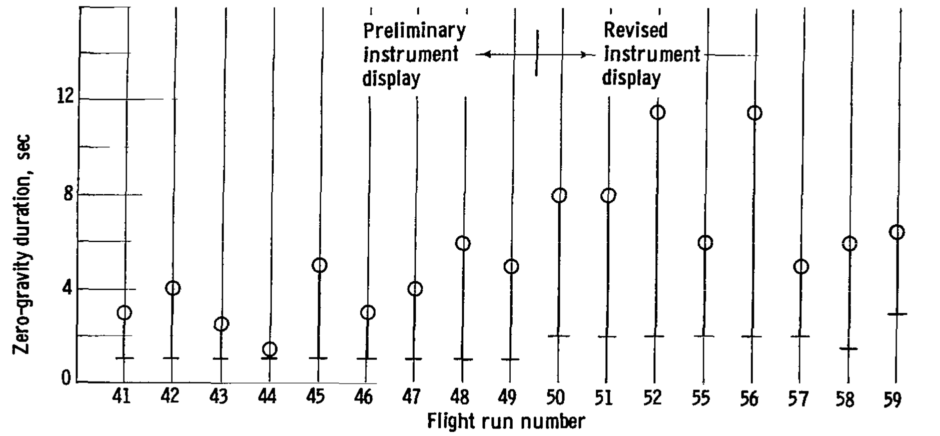

Figure 6. - Zero-gravity duration for free-float experiment aboard AJ2 aircraft. Improved performance with revised cockpit instrument display.

EXPERIMENT ACCOMMODATION

Three distinct modes of accommodating an experiment aboard the zero-gravity flight facility were employed and are as follows: (1) restrained, (2) free float, and (3) tethered. In the restrained mode, the experimental unit is secured to the airframe in such a fashion that the motion of the hardware relative to the airframe is precluded. The free-float mode uses the experiment as a completely self-contained unit, and it must be of such size and weight that it may be manually repositioned after each maneuver. Data collection is either on-board the experiment, or telemetered to a receiver within the aircraft. The tethered mode ideally retains some advantages of the free-float mode and is used when an experiment is so physically unwieldy and heavy that manual repositioning of the unit is impossible. This mode also permits a number of flexible leads to be used for data transmission to a recorder.

The restrained experiments suffer from the perturbations that disturb the airframe, so that the degree to which a true zero-gravity environment is approached is limited by the control input to the aircraft, atmospheric turbulence, wind gusts, and so forth. In general, acceleration levels of less than 0.01 g are not possible for more than 20 percent of the total zero-gravity exposure when the restrained mode is used. Longer periods of environment are possible, but with higher g levels, because the experiment is not constrained by the available compartment volume as in the free-float mode. Typical of this type of experiment would be large, heavy systems that would nearly fill the compartment. Heavily instrumented experiments requiring nonflexible umbilicals would also require use of the restrained mode. Systems which have remote components that are too unwieldy to integrate would be adaptable to the restrained mode because individual units could be placed in available space throughout the aircraft. This mode is particularly suitable for

Figure 7. - Restrained mode of installation of experiment studying liquid boiling and condensation mechanisms in zero-gravity environment.

Figure 8. - Tethered zero-gravity experiment installed aboard AJ2 aircraft.

small, high-performance aircraft such as a fighter or medium bomber. The majority of the experience aboard the AJ2 aircraft has been with the restrained type experiment, an example of which is shown in figure 7. This installation was used to study the condensation of mercury vapor in a long, tubular heat exchanger.

Tethered experiments use a means of relocating heavy free-float experiments or positioning them in a certain orientation for release on each trajectory. This was the earliest method of experiment accommodation used aboard the AJ2 aircraft facility. An example of a tethered installation aboard the aircraft is shown in figure 8. In this study, a fluid dynamics experiment, including a motion-picture camera, was self-contained. Only the power was supplied from outside the unit. The results were unsatisfactory because the disturbances introduced to the fluids by the elasticity of the suspension lines were large enough to invalidate the experiment. This experiment also required many attached cables for power and data transmission and the cables often became entangled in the tether lines and introduced further disturbances. Later, an experiment was flown in which the package was merely flown off the floor in a free-float mode. Improvement in the results was immediate in that the gravity-free duration was considerably extended.

Free-floated experiments have produced the best results as to diminution of the gravity acceleration. Various methods of handling the experimental package have been tried, but flying the package off the floor, that is, initially flying the airplane away from and then around the experiment, appears to be the most suitable. The free-floated package necessitates the presence of an attendant in the bomb bay to reposition it and to activate

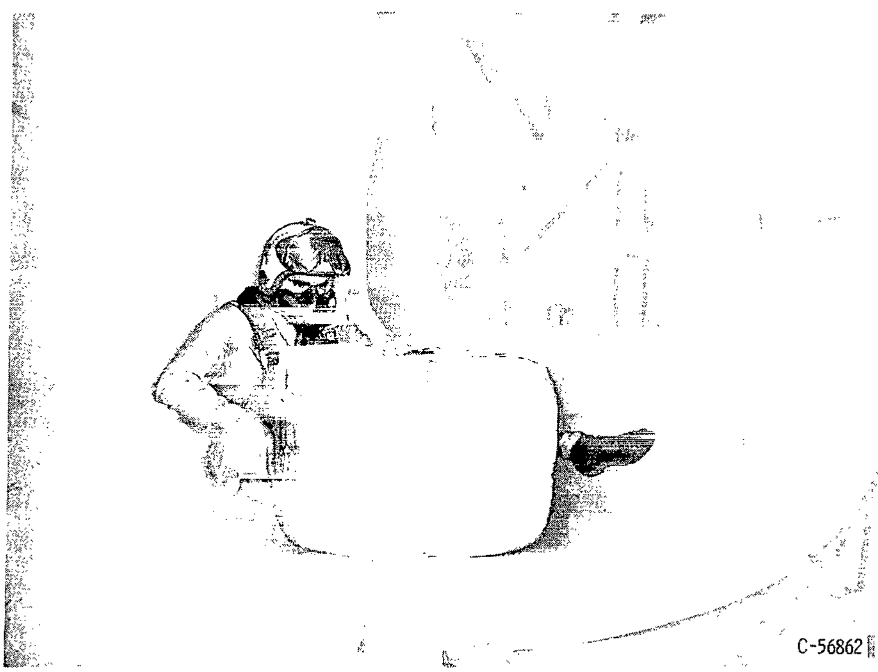

Figure 9. - Typical free-float experiment for zero-gravity environment.

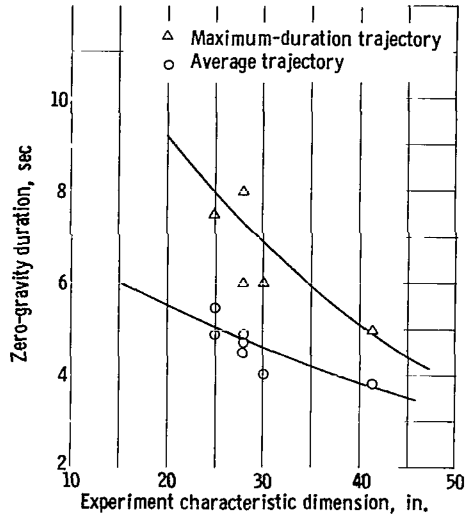

Figure 10. - Relation of experimental package size (longest diagonal) to free-float zero-gravity duration available in AJ2 aircraft bomb bay.

the data recorders. A typical free-float type of experiment is shown in figure 9. The experiment has been completely encased in a resilient plastic to protect the equipment.

The size of the experiment is an important factor in determining the duration of the free-float. Figure 10 shows the relation of the experimental package size to the free-float duration for the AJ2 aircraft. The experiment size is represented by a characteristic package dimension, that is, the longest diagonal. As can be seen from the figure, for any given accommodation space, packages over 45 inches across the longest diagonal cannot obtain more than about 4 seconds of gravity-free environment.

CONCLUDING REMARKS

Aside from the disadvantages peculiar to each of the restrained, free-float or tethered modes, there exist several overall limitations that must be considered in the use of an aircraft to produce a weightless environment for experimental purposes. The most important of these is that, by the nature of the maneuver, the dive and entry pullup, disturbances are introduced to the experiment before it enters the zero-gravity portion of the flight. Therefore, the experiment must be such that these initial disturbances are damped by the time the weightless period is achieved or that they do not introduce significant perturbations to the experiment. A second limitation exists in that the experiment must be fabricated so as to withstand the loadings introduced during the pullup portions of the maneuver. The gravity force at pullup and pullout can be reduced for delicate experiments, but requires some compromise of the weightless duration. An additional limitation of the aircraft as a zero-gravity facility is the minimum g level attainable by restrained experiments under the most ideal conditions. This level is of the order of 10^{-2} g and must be given consideration when fluid-behavior experiments are being planned for the facility.

Within the minimum g-level limitation imposed by the aircraft facility, this means of producing a weightless environment presents a method of achieving the desired condition for periods up to 90 seconds by the proper selection of mode of operation and aircraft test bed. The cost of producing the environment by use of an aircraft is several orders of magnitude less than when a rocket vehicle or an orbiting satellite is used. The aircraft also makes possible rapid repeatability of the test condition because as many as

20 to 30 test runs can be made per flight. Free fall facilities are usually severely limited in the number of test runs per day, and ballistic rockets require many months of preparation. For those experiments that require weightless durations that are extended and obtainable only aboard rockets or satellites, an aircraft can provide effective and economical means for making preliminary studies or systems checkouts prior to the use of the more expensive and elaborate facilities.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 9, 1965.

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NASA-Langley, 1966 E-2538

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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